

Studying the Stellar Populations of the Local Group with VLT

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1 Introduction

arXiv:astro-ph/9907029 2 Jul 1999

The best chance we have to understand star formation and how it proceeds in the Universe is going to come from detailed studies of the numerous different environments found within the Local Group (LG). Present day star formation in our Galaxy occurs exclusively in metal rich environments ($Z \sim Z_{\odot}$), so if we want to study how low metallicity stars form (and thus understand observations of galaxies at high-redshift) we have to look beyond our Galaxy, to the smallest star forming dwarf galaxies, which can have extremely low metallicities ($Z \sim 0.02 - 0.05 Z_{\odot}$). Of course in its entirety a stellar population always contains the complete details of the star formation history of a galaxy, however this information is often hard to disentangle retroactively. We also have much to learn from the Magellanic Clouds ($Z \sim 0.1 - 0.3 Z_{\odot}$), although because they are undergoing interactions with our Galaxy and each other their evolutionary picture and its general applicability less obvious. In our LG there are also a number of “remnants”, or galaxies which which currently do not form stars (*e.g.* the dSph, such as Carina, Leo I, Ursa Minor, etc.). It is not straight forward to draw parallels between galaxies which are forming stars and those which aren’t. This is of course because star formation has such a dramatic impact upon a galaxy, and alternative methods have to be used to make the most basic of comparisons of properties (*e.g.* metallicity, mass, luminosity evolution). It is necessary to put all the dwarf galaxies into a global picture if we are to draw meaningful conclusions about their star formation properties (*e.g.* Ferrara & Tolstoy 1999). Many of the small LG galaxies contain direct evidence of complicated star formation histories (*e.g.* Smecker-Hane *et al.* 1994; Tolstoy *et al.* 1998; Gallart *et al.* 1999), which suggests that star formation patterns can change dramatically over long time scales. This kind of evolutionary behaviour can have a dramatic impact upon the accurate interpretation of galaxy redshift surveys (cf. Tolstoy 1998).

As in all scientific endeavors the most useful approach to solving a complex question is to apply a number of different techniques, compare the results and then, with the help of some theoretical insight, form a consistent picture. The most important advances are likely to come not only from the ability to push fainter and deeper into interesting regions of the Colour-Magnitude diagram (CMD), but also from the ability to carry out detailed spectroscopic analyses of individual stars in the same CMDs. The first images and spectra to come

out of the Paranal Observatory from FORS1, (*e.g.* see Kudritski, this volume; Appenzeller, plenary talk), have offered the exciting two-fold promise: the ability to go very faint and exquisite image quality. This new era of the ground based 8-10m telescope promises to push forward our understanding of galaxy evolution via the study of nearby systems.

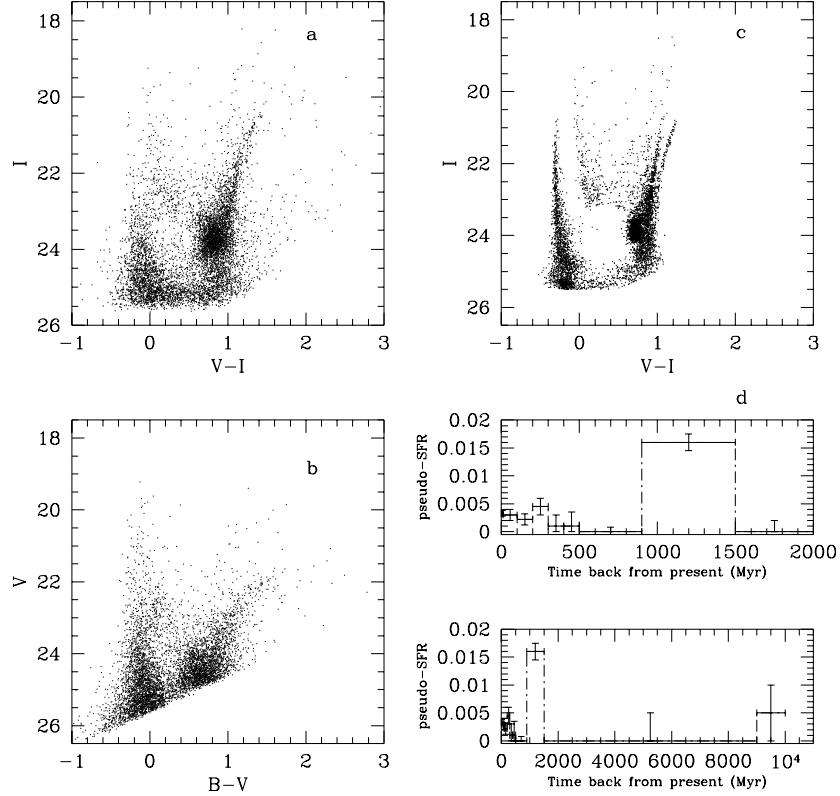


Fig. 1. Here are the results of the analysis of HST/WFPC2 data of nearby dwarf irregular galaxy Leo A (Tolstoy *et al.* 1998). In a. is the V-I, I CMD, 1 orbit exposure time per filter. In b. is the B-V, V CMD, 2 orbits in B. In c. is the best match Monte-Carlo simulation model (in V-I, I) found for these data convolved with the theoretical measurement error distribution, and in d. is the SFH that created the model CMD which best matches these data. See Tolstoy *et al.* (1998) for more details..

2 Colour-Magnitude Diagrams

The study of resolved stellar populations in CMDs as means of understanding the properties of nearby stars and galaxies has a distinguished historical tradition, going back to Leavitt almost a century ago, and including the careers of Hubble and Baade (*e.g.* Baade 1963). It was during the 1950's that the CMD provided the impetus to understand the, then, holy grail of stellar evolution, using the newly operating Palomar 200inch telescope, to observe Galactic star clusters. In the 1990s we have come so far that stellar evolution theory is understood in sufficient detail that we can make numerous predictions related to structures in a CMD (*e.g.* Bertelli *et al.* 1994; Tolstoy & Saha 1996; Girardi *et al.* 1996; Aparicio *et al.* 1996; Tolstoy 1999), based upon variations of age and metallicity in star forming regions many Gyr ago. Thus we have the ability to disentangle complex star formation histories of all nearby galaxies, with sufficiently deep and accurate CMDs.

Improved image quality is arguably of equal importance to an increase in aperture size. Digging deep in to a CMD is only a worthwhile exercise if the errors can be minimised. Much of the difficulty in interpreting CMDs comes from distinguishing effects which come from photometric errors due to image crowding and those caused by the star formation properties of a galaxy. The *Hubble Space Telescope* (HST) has been leading the way in providing high quality CMDs (*e.g.* Dohm-Palmer *et al.* 1997, 1998; Gallagher *et al.* 1998; Tolstoy *et al.* 1998; Cole *et al.* 1999; Gallart *et al.* 1999; see Figure 1), but the collecting area and instruments available on VLT will be important for further progress. In the case of low luminosity nearby galaxies HST images are completely uncrowded, and cover only a fraction of a galaxy, so using VLT can be an equally good option, given an average seeing of $\lesssim 0.6\text{arcsec}$ (*e.g.* see Fig 2). The resulting CMDs (Fig. 3) show a wealth of detail, and a much narrower red giant branch than previous observations. We also unequivocally define the presence blue main sequence stars in Antlia, with an age in the range 1-2 Gyr.

3 Metallicity Evolution

The global effects of stellar evolution upon the interstellar medium of a galaxy are surprisingly poorly understood, especially in metal poor environments. It is critical to our understanding of galaxy evolution to determine how the fraction of metals in a galaxy build up over time by the star formation process. This information is preserved in stellar abundance patterns of a galaxy, however distinguishing the effects of age and metallicity is often a complex task. Purely photometric determinations from CMD analysis cannot provide unique solutions because of age-metallicity degeneracy on the red giant branch. It is necessary to directly measure the abundance of a large sample stars to understand how the metallicity has Changed with time (*e.g.* Edvardsson *et al.* 1993, in our Galaxy). If we can add independent metallicity

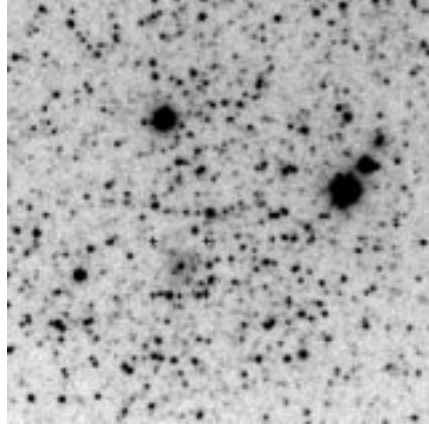


Fig. 2. This is the central section (50arcsec squared) of the combined I filter FORS1 images (total, 5400sec) of the Antlia dwarf galaxy taken under excellent seeing conditions on 30th and 31st January 1999. The average seeing was below 0.5 arcsec for the entire integration period. It can be seen that in this image crowding is not a problem, and the integrations could clearly be even longer. One point of note, is that an unusual source (in between the crosses here), remarked upon by Sarajedini *et al.* (1997), it is visible in the I band ($I \sim 22.5$) and not in the V ($V < 25$). It is clearly a background galaxy in the FORS1 image.

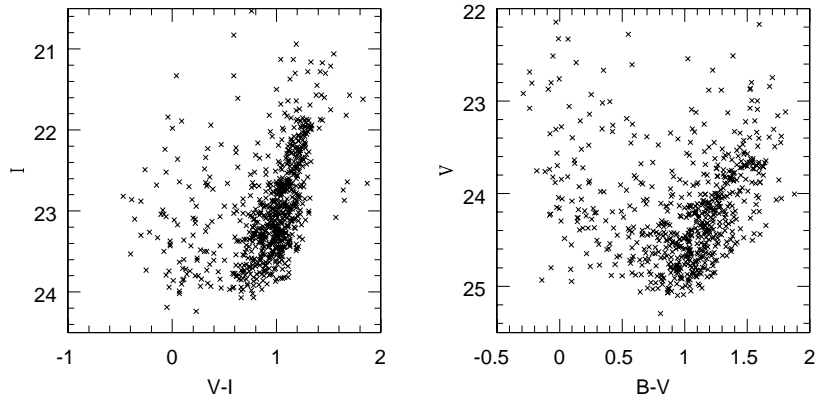


Fig. 3. Here we show the first CMDs from the FORS1 science verification data of the Antlia dwarf galaxy. They include stars within a circle of 3.3arcmin diameter centred on Antlia. The larger this area the more extensive will be the foreground contamination, but stars from Antlia are seen out to the edges of the FORS1 frame (7 arcmin across). The total integration times are 2400sec in B and V and 5400sec in I. There is a clear “blue plume” of stars, which is real. Inspection of the images shows that they are neither background galaxy confusion nor a cosmetic problem on the CCD. They could represent a comparatively young population of stars in Antlia (between 1 and 2 Gyr old). There is no evidence for extensive reddening internal to Antlia, but the calibrations used here are still preliminary. The (preliminary) distance from the tip of the red giant branch is 1.4 Mpc, slightly further away than previous estimates.

information about individual stars to CMD analysis, then we can determine much more accurate star formation histories.

There are several observational approaches to this problem, all of which benefit from intermediate and high resolution spectrographs on large telescopes (*e.g.* HIRES, FORS1/2, UVES). The large aperture of VLT or Keck is crucial to overcome the limitation of the readout noise of the detectors, which is the limiting factor on smaller telescopes.

- Metallicity evolution can be predicted from HII region emission line diagnostics with some success (*e.g.* Matteucci & Tosi 1985; Kobulnicky & Skillman 1996; Pagel & Tautvaišienė 1998), although this is not independent of uncertain model assumptions. There are also a number of LG galaxies with very faint HII regions about which we know very little about the basic abundance measures.
- The direct relation between the Ca II triplet absorption index and stellar metallicities in metal poor systems, as defined by Da Costa & Armandroff (1995), affords a convenient and independent way to measure the relative metallicities of evolved red giant stars, which cover the age range 1–10 Gyr. This has been successfully applied to stellar populations in the Magellanic Clouds (*e.g.* Olszewski *et al.* 1991; Da Costa & Hatzidimitriou 1998).
- In the case of the brighter giants in nearest by galaxies, higher resolution spectroscopy is possible for an accurate analysis of abundance patterns [*e.g.* McCarthy *et al.* 1995 (M31); Shetrone, Bolte & Stetson 1998 (Draco); Venn 1999 (SMC)]. These detailed abundance analyses provide an more accurate picture of how chemical enrichment occurs in different environments. For example, the pattern of element enrichment (*e.g.* C, N, O, Na, Mg and Al to Fe) in globular cluster giants is found to differ from field Population II giants in the Galaxy halo (Pilachowski, Sneden & Kraft 1996; Shetrone 1996).

4 Summary

The power of high quality images and large collecting area of the VLT is impressive, and there are clearly many exciting discoveries waiting to be made. We hope for further steps forward from the study of resolved stellar populations with VLT, as from Palomar before it, because now we will be able to probe a much large range of star forming environment within the LG, and specifically very low metallicity environments. The tremendous gains in image quality and collecting area now available with the VLT on Paranal make it important to survey the resolved stellar populations of all the accessible galaxies in our LG. This will provide a uniform picture of the properties of stellar populations of galaxies with a wide variety of mass, metallicity, gas content etc. This has begun with FORS1 science verification observations in

January 1999, with BVI images of the LG galaxy Antlia (see Fig. 3). The study of individual stars and star-formation regions in the nearby universe is the only way we will understand the observations of galaxy populations at high redshift.

Acknowledgments: The Science Verification data used in this paper are public, and were not presented at the Antofagasta meeting (only as press release images by Prof. I. Appenzeller in his plenary talk), the analysis here was made after the data were made public in May 1999. For more information, look at the ESO web page: <http://www.eso.org/science/ut1sv/>

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